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# Electronic Measurement of a Clinical Quality Measure for Inpatient Hypoglycemic Events: A Multicenter Validation Study

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## Abstract

**Background:** Hypoglycemia related to anti-diabetic drugs (ADDs) is an important iatrogenic harm in hospitalized patients. Electronic identification of ADD-related hypoglycemia may be an efficient, reliable method to inform quality improvement.

**Objectives:** Develop electronic queries of electronic health records (EHRs) for facility-wide and unit-specific inpatient hypoglycemia event rates and validate query findings with manual chart review.

**Methods:** Electronic queries were created to associate blood glucose (BG) values with ADD administration and inpatient location in three tertiary-care hospitals with Patient Centered Outcomes Research Network (PCORnet) databases. Queries were based on National Quality Forum (NQF) criteria with hypoglycemia thresholds <40 mg/dL and <54 mg/dL, and validated using a stratified random sample of 321 BG events. Sensitivity and specificity were calculated with manual chart review as the reference standard.

**Results:** The sensitivity and specificity of queries for hypoglycemia events were 97.3% (95% CI, 90.5%-99.7%) and 100.0% (95% CI, 92.6%-100.0%) respectively for BG <40 mg/dL, and 97.7% (95% CI, 93.3%-99.5%) and 100.0% (95% CI, 95.3%-100.0%) respectively for <54 mg/dL. The sensitivity and specificity of the query for identifying ADD days were 91.8% (95% CI, 89.2%-94.0%) and 99.0% (95% CI, 97.5%-99.7%). Of 48 events missed by the queries, 37 (77.1%) were due to incomplete identification of insulin administered by infusion. Facility-wide

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hypoglycemia rates were 0.4%-0.8% (BG <40 mg/dL) and 1.9%-3.0% (BG <54 mg/dL); rates varied by patient care unit.

**Conclusions:** Electronic queries can accurately identify inpatient hypoglycemia. Implementation in non-PCORnet-participating facilities should be assessed, with particular attention to patient location and insulin infusions.

## INTRODUCTION

Inpatient hypoglycemia can be life-threatening, and is associated with longer hospital stays and increased medical costs.[1–5] Severe hypoglycemia (<40 mg/dL) occurs in 2–5% of hospitalized patients with diabetes mellitus,[5–8] and medication-related hypoglycemic events are common causes of adverse drug events occurring in inpatient settings.[9] Up to half of inpatient adverse drug events may be preventable,[10] and recent studies show that rates of severe hypoglycemia vary across hospitals, suggesting opportunities for improved care.[11]

In 2014, the National Quality Forum (NQF) endorsed an electronic clinical quality measure (eCQM) for hospital-wide inpatient hypoglycemia reporting (NQF 2363) and recommended use of the measure in Centers for Medicare & Medicaid Services (CMS) inpatient quality reporting programs.[12] While NQF 2363 was intended to support reliable and timely measurement of hypoglycemia event rates, its implementation has been limited by costs associated with paying third parties to extract electronic health record (EHR) data, inconsistent adoption of standard nomenclatures and mapping terms across hospital systems, and complexity of the query necessary to generate the measure. Moreover, disagreement persists regarding threshold values that should be used for hypoglycemia quality measures. A blood glucose threshold of <40 mg/dL is recommended by NQF for adverse event reporting in clinical trials, whereas a threshold of <54 mg/dL is recommended by the American Diabetes Association (ADA).[13]

One approach to facilitating implementation of eCQMs involves adoption of a standardized format or common data model, which uses normalized databases and standard vocabularies to represent clinical conditions, laboratory results, medications and other information, in addition to shared query tools among facilities to generate summary data. In this report, we describe the development and validation of electronic queries to measure inpatient hypoglycemia with the NQF 2363-defined blood glucose threshold (<40 mg/dL) and an alternative threshold (<54 mg/dL) using the Patient Centered Outcomes Research Network (PCORnet) common data model.[14,15] PCORnet is comprised of clinical data research networks representing over 300 healthcare-delivery systems that participate in multi-network studies using shared informatics and governance structures.[16] Electronic queries in this study were tested in three medical centers with PCORnet normalized databases and standard vocabularies, validated through manual chart review, and refined based on feedback from hospital sites. The PCORnet data tables from all three hospitals were used to identify electronic medication administration record (eMAR) data to capture anti-diabetic drug (ADD) information, and laboratory test data to capture blood glucose results. For this project, we augmented the common data model with a bed information table to track patient movement in the hospital.

# METHODS

## Participating Sites and Coordinating Center.

The participating sites were three large, tertiary-care centers that participated in PCORnet; none had previously implemented the NQF 2363 measure. The coordinating center was the Medical Research Analytics and Informatics Alliance (MRAIA). The study was classified as minimal risk, and approved by the Chicago Area Institutional Review Board and individual hospital IRBs according to local requirements.

## NQF 2363 Measure Components and Rate Calculation.

The numerator was defined as hypoglycemic events (<40 mg/dL or <54 mg/dL) preceded by administration of rapid or short-acting insulin within 12 hours or an ADD other than short-acting insulin within 24 hours, and not followed by a glucose value >80 mg/dL within 5 minutes, and at least 20 hours apart (Table 1). The designation of “fasting” on glucose values was unreliable and therefore not used as an exclusion criterion. Also, we eliminated the 120-day length of stay exclusion because such events are rare, have no clear biological rationale, and complicate timely surveillance reporting. The denominator was defined as an ADD day, which is an inpatient day with at least one ADD administered. All inpatients on ADDs contributed to the denominator regardless of whether the patient experienced a hypoglycemic event. We excluded patients on observation status and those in psychiatric and rehabilitation units from both the numerator and denominator. The inpatient hypoglycemia rate for a defined period was the percentage of total number of events meeting the numerator case definition divided by the total number of ADD days.

## Identification of EHR Data Elements.

Blood glucose measurements were identified using Logical Observation Identifiers Names and Codes (LOINC) terms at Hospital C (Supplemental Table 1), whereas Hospitals A and B did not have LOINC terms mapped in the laboratory information system. Hospitals A and B generated a list of laboratory test names containing the word ‘glucose’, excluded tests that were obviously not blood glucose such as urine or cerebrospinal fluid glucose, validated remaining tests by checking a sample of actual results in the EHR, and mapped tests determined to be blood glucose measurements to selected LOINC terms.[17] A list of ADDs mapped to RXNORM ingredient codes was generated centrally and distributed to sites, and included all FDA-approved formulations of ADDs (Supplemental Table 1).[18] This list was then used to identify ADDs by drug name, formulation and administration date-time. Bed information was not in the PCORnet common data model and had to be populated using admission-discharge-transfer information from the EHR.[19] Inpatient movement was captured in bed information tables mapped to location types specified by the National Healthcare Safety Network (NHSN).[20]

## Electronic Query Development (Figure 1).

SQL-based electronic queries were developed to identify index blood glucose events and ADD days based on modified NQF criteria and distributed to sites through GitHub.[21] Query development was performed by the programmer author (HZ), in cooperation with physician-

epidemiologist authors (CC and WT). NQF hypoglycemia measure criteria were discussed in detail, RxNorm and LOINC mappings for ADDs and blood glucose values were reviewed, and a random sample of clinical data from Hospital A was used to ensure that query logic was correct by comparing query results to manual review. These queries were written in the form of Transact Structured Query Language (T-SQL).

### Manual Chart Review Validation (Figure 1).

For each site, stratified random sampling for manual chart review was performed in three steps among inpatients who received ADDs between January 1, 2016 and December 31, 2016: 1) randomly select 40 patients with blood glucose ≤53 mg/dL, 2) randomly select an additional number of patients with blood glucose <40 mg/dL to have 40 patients with blood glucose <40 mg/dL, and 3) randomly select 40 patients with blood glucose ≥54 mg/dL. Events were sampled without replacement, i.e., patients were only sampled once. The sample size for validation was based on estimating sensitivity and specificity with a margin of error of ≤0.05. We assumed the electronic query would have 95% sensitivity and 95% specificity compared to the reference standard (manual chart review), and up to 5% of sampled patients might be excluded (e.g., due to measure exclusions). Blood glucose events were used for numerator validation, and the first three inpatient days were used for denominator validation. Manual chart review was considered the reference standard for determining if electronically-generated numerator and denominator data conformed to the modified NQF criteria. A chart abstraction tool was developed independently from the electronic query by a physician-epidemiologist author (CC) with assistance from an endocrinologist author with glucometrics expertise (YG); this was done prior to developing the electronic query to capture the measure. Chart abstractors were trained in a two-hour session by the physician-epidemiologist author (CC). Chart abstractors trained on the study protocol and blinded to query results reviewed both structured data in the EHR (e.g. laboratory results and ADD administration records) as well as unstructured free text notes. An endocrinologist author with glucometrics expertise (YG) addressed questions from chart abstractors during reviews. An epidemiologist author (NK) developed a REDCap data entry tool,[22] and chart abstractors entered manually extracted EHR data into the tool. Comparisons between findings from manual chart abstraction in REDCap and the electronic query output were done centrally by MRAIA. Each blood glucose event and ADD day were classified as either manual chart review positive or negative (MCR+/MCR-) or electronic clinical quality measure positive or negative (eCQM+/eCQM-). For instances where there were discrepancies between REDCap data and the electronic query output, manual chart abstraction was repeated to confirm accuracy of data extraction and entry. Persistent discrepancies after the second round of manual chart abstraction were evaluated by a third round of manual chart abstraction with in-person assistance from the epidemiologist author (NK) at Hospitals A and B.

### Electronic Queries for Hospital-Wide and Unit-Specific Measure Data (Figure 1).

Queries and databases were re-evaluated based on feedback from manual chart review. To generate hospital-wide and unit-specific hypoglycemia measures based on modified NQF criteria, we distributed the queries to each site through GitHub.[21] Query and database re-evaluation was performed by the programmer author (HZ). Although the queries were

optimized to address variability in EHR terminologies across sites (e.g., ADDs and laboratory tests mapped to the correct codes), we did not restructure the databases to better capture EHR transactions (e.g. insulin drips); we allowed such limitations to be discovered and reported to improve implementation by other sites. Unit-level hypoglycemia rates were measured based on where hypoglycemic events occurred (specimen collection date-time), rather than where preceding ADDs were administered.

### Statistical analysis.

We determined the sensitivity and specificity of the original electronic query with manual chart review as the reference standard, and calculated Clopper-Pearson (exact) confidence intervals (CIs) around the performance attributes. Pairwise comparisons of electronically generated hospital-wide event rates were performed using t-tests. All statistical analyses of manually extracted data and electronic query output were performed using SAS 9.4 (SAS Institute, Cary, NC).

## RESULTS

### Manual Chart Review Validation: Numerator

A total of 321 blood glucose events were identified and used to validate the numerator component of the quality measure. Of these blood glucose events, 119 (37.1%) were <40 mg/dL, 85 (26.5%) were 40–53 mg/dL and 117 (36.4%) were ≥54 mg/dL (Table 2). Of 119 events with blood glucose <40 mg/dL identified by manual chart review, two were not identified by the electronic query (eCQM-/MCR+) (Table 3). Of 85 events with blood glucose 40–53 mg/dL, one was not identified by the electronic query (eCQM-/MCR+). In all three instances, the electronic query did not identify insulin administered by infusion (insulin drip). No misclassifications occurred among the 117 blood glucose events that were ≥54 mg/dL. The sensitivity and specificity of the electronic process for identifying events with blood glucose <40 mg/dL that met NQF numerator criteria were 97.3% and 100% respectively. The sensitivity and specificity of the electronic process for identifying events with blood glucose <54 mg/dL that met NQF numerator criteria were 97.7% and 100% respectively (Table 3).

### Manual Chart Review Validation: Denominator

A total of 959 patient-days from the first three inpatient days for 321 randomly selected patients were used to validate the denominator component of the quality measure (Table 3). Of these patient-days, 45 (4.7%) were not identified as ADD days by the electronic query when ADDs were identified by manual chart review (eCQM-/MCR+). Thirty-four (75.6%) of these 45 instances involved insulin drips (7 at Hospital A, 9 at Hospital B, 18 at Hospital C), whereas 11 (24.4%) were discordant for unknown reasons (all at Hospital C) despite multiple attempts to reconcile the results. Of 959 patient-days, four (0.4%) were identified as ADD days by the electronic query when no ADD administration was identified by manual chart review (eCQM+/MCR-). The reason for discordance in these four instances could not be determined (all at Hospital C). The sensitivity and specificity of the electronic query in identifying ADD days as defined by NQF denominator criteria was 91.8% and 99.0% respectively.

Further investigation into why insulin drips were missed by the query was performed in Hospital A. It was found that continuous infusions in hospital A's data warehouse had a separate indicator that reflected medication administration only on infusion initiation or a change in infusion rate. Thus, when the same insulin dose was continuously administered over the course of multiple hours or days, medication administration was not transmitted to the PCORnet data warehouse and insulin administration was not recorded. When the requirement for the indicator was omitted for continuous infusions, five of seven discrepancies between manual chart review and the electronic query at Hospital A were resolved; however, we did not use this correction to recalculate performance characteristics. The two remaining misclassifications resulted from insulin drip details being entered into the system episodically, and not every minute. This led to the query mistakenly classifying a hospital day as a non-ADD day when patients were started on insulin infusions close to midnight but not electronically recorded until after midnight, when insulin drip administration was updated.

### Hospital-Wide and Unit-Specific eCQM Data

The validated and fully electronic queries were distributed to sites and hospital-wide and unit-specific hypoglycemia event rates for 2016 were determined (Table 4). Hospital-wide hypoglycemia rates defined as blood glucose events <40 mg/dL were 0.7%, 0.8%, and 0.4% for Hospitals A, B and C respectively, and hospital-wide hypoglycemia rates defined as blood glucose events <54 mg/dL were 2.3%, 3.0%, and 1.9% for Hospitals A, B, and C respectively. All pairwise comparisons showed statistically significant differences in hypoglycemia event rates among hospitals ($p < 0.05$). Medical intensive care unit-specific hypoglycemia rates were 0.7% and 1.6% for blood glucose <40 mg/dL, and 1.7% and 4.6% for blood glucose <54 mg/dL for Hospitals A and B, respectively. Surgical intensive care unit-specific hypoglycemia rates were 0.1% and 0.8% for blood glucose <40 mg/dL, and 1.5% and 3.4% for blood glucose <54 mg/dL for Hospitals A and B respectively. Unit-specific information was not available from Hospital C.

## DISCUSSION

Results from this study in three tertiary care hospitals demonstrate that fully electronic queries based on a clinical quality measure can accurately identify inpatient hypoglycemia events and rates. The queries demonstrated very good performance in identifying the quality measure numerator (hypoglycemia events) and the quality measure denominator (ADD days). Facility-wide and unit-specific hypoglycemia rates showed statistically significant variation across hospitals and comparable intensive care units.

While highly accurate, instances of misclassification occasionally occurred with the queries. Misclassification primarily resulted from failure of the queries in detecting all instances where insulin was administered by continuous infusion (insulin drips). Further investigation at Hospital A showed that this related to an underlying database issue that flagged insulin administration only on infusion initiation or a change in infusion rate, and intermittent and irregular documentation of insulin infusions in the EHR, which translated to less than up-to-the-minute capture of insulin administration in the PCORnet data warehouse. Insulin

infusion is a recommended strategy for glycemic management in critically ill patients.[23] Ensuring accurate capture of these types of medication administration events will be important for quality measurement and improvement efforts, especially for intensive care units. Query misclassification from failed detection of insulin drips could bias hospitals with poor capture of insulin infusion information to falsely low hypoglycemia rates relative to hospitals where ADD administration and days are captured accurately.

There were 15 instances (11 eCQM-/MCR+ and 4 eCQM+/MCR-) in which misclassification was not due to failed detection of insulin drips; all in Hospital C. Reasons for these remaining discrepancies likely included incomplete capture of EHR data in the research database or chart abstraction errors. Database errors may have been due to inaccurate information in the hospital clinical data warehouse (e.g., time stamp error) or inaccurate or incomplete information in the PCORnet data warehouse due to errors during the extract-transform-load (ETL) process (e.g., date-time shifting).

Although we undertook extensive review of manually-entered data to address potential chart abstraction errors, errors on chart review (e.g. date-time errors) or REDCap data entry may still have been possible. Indeed, we found that the manual chart review process was prone to error, with more than 60 instances of chart abstraction or data entry inconsistencies that were identified and subsequently corrected during adjudication with query results. The chart abstraction errors we identified underscore the fallibility of manual methods for surveillance and the importance of validated electronic approaches for hospital surveillance data.[24]

A blood glucose threshold of <54 mg/dL recommended by the ADA[13] produced three to four-fold higher measurements of inpatient hypoglycemia compared to the quality measure-defined blood glucose threshold of <40 mg/dL in the three participating hospitals. Given that even blood glucose <70 mg/dL can indicate clinically important hypoglycemia,[25] quality improvement at higher thresholds of hypoglycemia should be considered. Additionally, recent data suggest that blood glucose values between 45 mg/dL and 93 mg/dL on the last day of hospitalization are associated with higher rates of 30-day readmission (<93 mg/dL) and post-discharge mortality (<45 mg/dL and <67 mg/dL),[26] underscoring the importance of surveillance and quality measurement at more than one blood glucose threshold.

Substantial variation in inpatient hypoglycemia rates was found among the three participating sites, and among comparable intensive care units between sites. Such variation indicates potential opportunities for improvement through inter-institutional rate comparisons (benchmarking). It is unclear whether this variability is due to differences in quality of care, or differences in patient case-mix (e.g., patient age or renal dysfunction) and severity of illness. Risk adjustment, similar to what is utilized for reporting and benchmarking healthcare-associated infections in NHSN, could be considered to adjust for variability in patient populations across hospitals.[27]

After this study was initiated, NQF 2363 hypoglycemia measure underwent minor re-specifications by CMS.[28] The newer proposed measure is an incidence proportion of patients with hypoglycemia <40 mg/dL who received an ADD within 24 hours not followed by a blood glucose result >80 mg/dL within 5 minutes among all hospital inpatient

admissions. In contrast, the NQF-measure is an incidence rate of hypoglycemic events over ADD days, rather than patient-admissions, and allows for repeat events >20 hours apart. The newly proposed measure also does not distinguish between short- and long-acting ADD preparations. We successfully developed fully electronic queries that accurately counted hypoglycemic events and ADD days according to current NQF criteria, indicating that implementation challenges can be overcome from the technical perspective. Identification of repeat hypoglycemic events is especially important since prior episodes can portend future episodes,[29] and should trigger programmatic review.[30] Consideration should be given to measurement of repeat hypoglycemic events since these events appear fully amenable to electronic capture. Additionally, our findings demonstrated variability in hypoglycemia event rates among different patient care units. Similar to other hospital-acquired adverse events, such as healthcare-associated infections,[31] unit-level measurements and comparisons will be important for benchmarking medication-related hypoglycemia.

Our approach to electronic capture of hypoglycemic events has some limitations. First, the quality measure on which the electronic query was based may not perfectly distinguish between iatrogenic and non-iatrogenic hypoglycemia. Other conditions (e.g., shock, liver failure) likely contributed to hypoglycemia in some patients, particularly during the last 48 hours of life; however, ADDs were administered before these hypoglycemic events and likely were contributory. Second, two of three facilities in our study did not have LOINC terms for laboratory tests, and not all local test names definitively identified specimen source. A manual process was required to verify which glucose results were blood glucose results. This is largely a reflection of lack of standardization in laboratory test terminology across EHRs; however even with use of standard vocabularies, like LOINC, validation to ensure that LOINC mappings are inclusive of specimen source, such as urine or blood, may still be needed. Third, we chose not to have more than one independent manual chart review at each site to compute inter-annotator agreement; however, we did perform a third round of manual chart review for circumstances of disagreement between data entry based on chart review and electronic query results.[19,24] Fourth, despite multiple efforts to resolve discordant data between manual chart abstraction and the electronic query, there remained a subset of discrepancies for which the origin could not be fully identified. However, the absolute number of these events was low, representing only 1.1% of sampled inpatient days and all occurring at Hospital C. Discrepant data at Hospital C included uncommon episodes of ADD administration present in the EHR but not captured in the PCORnet data warehouse; the converse was also present, but rare. It may have been possible to reload Hospital C data to the research warehouse, but this would not have represented a real-world application of the electronic query. While we hoped for complete data capture from all three research data warehouses, having a small percentage of missing values was consistent with our expectations. We believe these findings are representative of real-world conditions and reinforce the need for validation of data capture in future work. Lastly, our approach is not intended to generate real-time data, which are helpful for acute clinical care interventions by diabetes programs (e.g., identification of patients for whom expert input regarding ADD dosing is necessary). However, electronic surveillance of hypoglycemia quality measures does not preclude simultaneous use of other methods (e.g., EHR-generated alerts to the endocrine service) to support immediate clinical interventions. Despite these limitations, we

demonstrated that fully electronic queries for measuring NQF 2363 were highly accurate in capturing inpatient hypoglycemia events and rates across hospitals that mapped their data to an augmented PCORnet common data model.

Use of common data models has the potential to foster standardized and efficient capture of electronic quality measures across the United States and elsewhere. Further work on electronic hypoglycemic measurement could involve reuse of our query in additional facilities that either share common data models or vendor systems, and testing in facilities outside of PCORnet. This would allow for more opportunities to improve the current query (e.g., better capture of insulin drips), and greater understanding of the variability of hypoglycemia rates across hospitals and unit types. Future work could also further address the epidemiology of hypoglycemic events at the level of the individual event or through an ecologic analysis. For example, factors associated with hypoglycemia can be elucidated, which could inform predictive models to determine expected event rates; such work could be facilitated through a common data model. Additionally, a quality measure for inpatient hyperglycemia (NQF 2362), has also recently undergone re-specification by CMS.[12] Future work could similarly address electronic capture and validity of this hyperglycemia measure. Moving forward, quality improvement efforts should include both measures so that initiatives to reduce hypoglycemic events do not result in increased hyperglycemic events.

In summary, fully electronic queries were highly accurate in capturing inpatient hypoglycemia events and rates across hospitals with different EHR systems that mapped their data to an augmented PCORnet common data model. Such interoperability has the potential to extend hypoglycemia measurement to additional hospitals. More widespread implementation of the NQF hypoglycemia measure can inform patient safety programs within institutions, provide opportunities for benchmarking across institutions, and contribute towards decreasing harmful and potentially fatal hypoglycemic events in hospitals.

## Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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## REFERENCES

1. Krinsley J, Schultz MJ, Spronk PE, et al. Mild hypoglycemia is strongly associated with increased intensive care unit length of stay. Annals of intensive care. 11 24 2011;1:49. [PubMed: 22115519]
2. Egi M, Bellomo R, Stachowski E, et al. Hypoglycemia and outcome in critically ill patients. Mayo Clinic proceedings. 3 2010;85(3):217–224. [PubMed: 20176928]
3. Krinsley JS, Schultz MJ, Spronk PE, et al. Mild hypoglycemia is independently associated with increased mortality in the critically ill. Critical care. 7 25 2011;15(4):R173.
4. Nirantharakumar K, Marshall T, Kennedy A, Narendran P, Hemming K, Coleman JJ. Hypoglycaemia is associated with increased length of stay and mortality in people with diabetes

who are hospitalized. Diabetic medicine : a journal of the British Diabetic Association. 12 2012;29(12):e445–448. [PubMed: 22937877]

5. Turchin A, Matheny ME, Shubina M, Scanlon JV, Greenwood B, Pendergrass ML. Hypoglycemia and clinical outcomes in patients with diabetes hospitalized in the general ward. Diabetes care. 7 2009;32(7):1153–1157. [PubMed: 19564471]
6. Cook CB, Kongable GL, Potter DJ, Abad VJ, Leija DE, Anderson M. Inpatient glucose control: a glycemic survey of 126 U.S. hospitals. Journal of hospital medicine. 11 2009;4(9):E7–E14.
7. Nirantharakumar K, Marshall T, Hodson J, et al. Hypoglycemia in non-diabetic in-patients: clinical or criminal? PloS one. 2012;7(7):e40384.
8. Wexler DJ, Meigs JB, Cagliero E, Nathan DM, Grant RW. Prevalence of hyper- and hypoglycemia among inpatients with diabetes: a national survey of 44 U.S. hospitals. Diabetes care. 2 2007;30(2):367–369. [PubMed: 17259511]
9. Classen DC, Jaser L, Budnitz DS. Adverse drug events among hospitalized Medicare patients: epidemiology and national estimates from a new approach to surveillance. Joint Commission journal on quality and patient safety. 1 2010;36(1):12–21. [PubMed: 20112660]
10. OIG. Adverse events in hospitals: national incidence among Medicare beneficiaries. 2010;Report No. OEI-06–09-00090.
11. Maynard G, Ramos P, Kulasa K, Rogers KM, Messler J, Schnipper JL. How Sweet Is It? The Use of Benchmarking to Optimize Inpatient Glycemic Control. Diabetes spectrum : a publication of the American Diabetes Association. 8 2014;27(3):212–217. [PubMed: 26246782]
12. Centers for Medicare & Medicaid Services. CMS Measures Inventory Tool. Glycemic Control – Hypoglycemia. https://cmit.cms.gov/CMIT_public/ViewMeasure?MeasureId=3180.
13. International Hypoglycaemia Study G Glucose Concentrations of Less Than 3.0 mmol/L (54 mg/dL) Should Be Reported in Clinical Trials: A Joint Position Statement of the American Diabetes Association and the European Association for the Study of Diabetes. Diabetes care. 1 2017;40(1):155–157. [PubMed: 27872155]
14. Qualls LG, Phillips TA, Hammill BG, et al. Evaluating Foundational Data Quality in the National Patient-Centered Clinical Research Network (PCORnet(R)). Egems. 4 13 2018;6(1):3. [PubMed: 29881761]
15. Kho AN, Hynes DM, Goel S, et al. CAPriCORN: Chicago Area Patient-Centered Outcomes Research Network. Journal of the American Medical Informatics Association : JAMIA. Jul-Aug 2014;21(4):607–611. [PubMed: 24821736]
16. https://pcornet.org/.
17. CMS. https://www.cms.gov/Medicare/Quality-Initiatives-Patient-Assessment-Instruments/QualityMeasures/index.html.
18. Peters LB, Bodenreider O. Approaches to Supporting the Analysis of Historical Medication Datasets with RxNorm. AMIA ... Annual Symposium proceedings. AMIA Symposium 2015;2015:1034–1041.
19. Patel MT, Santos C, Price R, Nelson G, Hall L, Platt R, Trick W Data Model for Initiatives to Monitor Exposure to Antimicrobials (DataMIME). Online Journal of Public Health Informatics. 2018;10(1):e35.
20. Wright MO, Decker SG, Allen-Bridson K, Hebden JN, Leaptrot D. Healthcare-associated infections studies project: An American Journal of Infection Control and National Healthcare Safety Network data quality collaboration: Location mapping. American journal of infection control. 5 2018;46(5):577–578. [PubMed: 29449023]
21. https://github.com/CollaborativeResearchUnit/CHIN-UP.
22. Harris PA, Taylor R, Thielke R, Payne J, Gonzalez N, Conde JG. Research electronic data capture (REDCap)--a metadata-driven methodology and workflow process for providing translational research informatics support. Journal of biomedical informatics. 4 2009;42(2):377–381. [PubMed: 18929686]
23. Moghissi ES, Korytkowski MT, DiNardo M, et al. American Association of Clinical Endocrinologists and American Diabetes Association consensus statement on inpatient glycemic control. Endocrine practice : official journal of the American College of Endocrinology and the American Association of Clinical Endocrinologists. May-Jun 2009;15(4):353–369.

24. Lin MY, Hota B, Khan YM, et al. Quality of traditional surveillance for public reporting of nosocomial bloodstream infection rates. Jama. 11 10 2010;304(18):2035–2041. [PubMed: 21063013]

25. Brodovicz KG, Mehta V, Zhang Q, et al. Association between hypoglycemia and inpatient mortality and length of hospital stay in hospitalized, insulin-treated patients. Current medical research and opinion. 2 2013;29(2):101–107. [PubMed: 23198978]

26. Spanakis EK, Umpierrez GE, Siddiqui T, et al. "Association of glucose concentrations at hospital discharge with readmissions and mortality: A nationwide cohort study.". The Journal of clinical endocrinology and metabolism. 5 1 2019.

27. The NHSN Standardized Infection Ratio. https://www.cdc.gov/nhsn/pdfs/ps-analysis-resources/nhsn-sir-guide.pdf.

28. CMS. https://www.glytecsystems.com/images/documents/hypoglycemia-cms-measure-specification.pdf.

29. Hulkower RD, Pollack RM, Zonszein J. Understanding hypoglycemia in hospitalized patients. Diabetes management. 3 2014;4(2):165–176. [PubMed: 25197322]

30. Maynard G, Berg K, Kulasa K, O'Malley C, Rogers KM (editors). The Glycemic Control Implementation Guide: Improving Glycemic Control, Preventing Hypoglycemia and Optimizing Care of the Inpatient with Hyperglycemia (2nd edition). 2015.

31. Centers for Disease Control and Prevention. Mapping locations for NHSN surveillance: preparing for 2013. https://www.cdc.gov/nhsn/pdfs/training/analysis/mapping-locations-nhsn-surveillance-508.pdf.

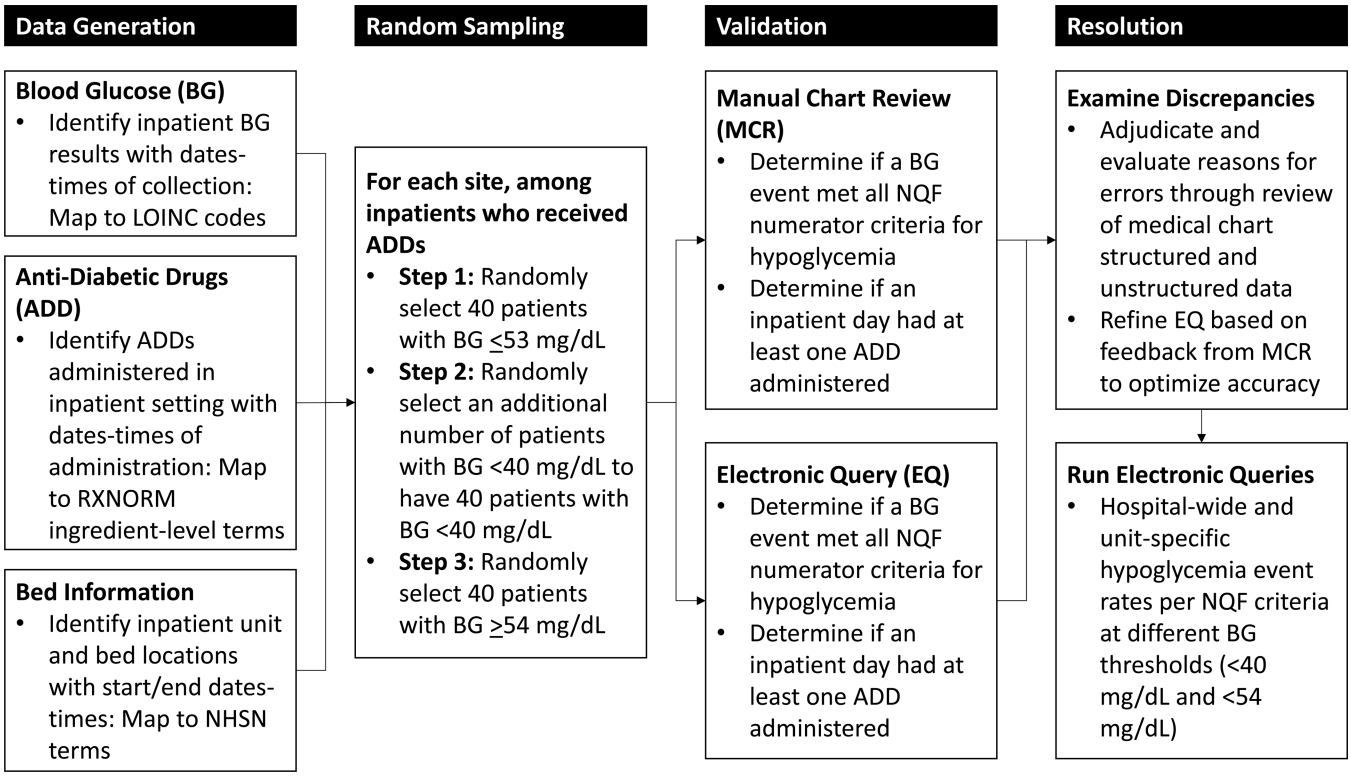


**Figure 1. Overview of study design and implementation for electronic measurement of a clinical quality measure for inpatient hypoglycemic events.**

**Table 1.**

NQF Measure 2363 – Glycemic Control, Hypoglycemia: Measure Components and Event Rate Calculations

| Measure Component | Measure Criteria | Description | Study Modification* |
|---|---|---|---|
| **Numerator** | Hypoglycemic events (BG <40 mg/dL) that:<br>• are preceded by administration of rapid or short acting insulin within 12 hours, or preceded by an ADD† other than short-acting insulin within 24 hours, and<br>• not followed by a BG value >80 mg/dL within five minutes, and<br>• are at least 20 hours apart | • Eligible tests: random or peri-prandial blood glucose (capillary, serum, plasma, whole blood)<br>• Excluded glucose tests: fasting or post-glucose<br>• Both laboratory and point-of-care glucose tests are required | • An additional BG threshold of <54 mg/dL was added<br>• Fasting glucose tests were not excluded |
| **Denominator** | ADD day: an inpatient day with at least one ADD administered | All inpatients on ADDs contribute to the denominator, regardless of whether or not the patient experienced a hypoglycemic event | No modification |
| **Exclusions** | Admissions with lengths of stay (LOS) greater than 120 days | | • Patients with LOS > 120 days were not excluded<br>• BG and ADD data from patients on observation, or in psychiatric and rehabilitation units were excluded |
| **Event Rate** | Total number of BG events meeting numerator case definition x 100 / Total number of ADD days | Expressed as % for a defined time period | No modification |

*Refers to modifications to the NQF measure criteria that were made in developing and validating the electronic queries.

†Anti-diabetic drugs included all Food and Drug Administration-approved formulations of insulin, alpha glucosidase inhibitors, amylin analogs, biguanides (metformin), dipeptidyl peptidase 4 inhibitors, glucagon-like peptide-1 (GLP-1) receptor agonists, meglitinides, sodium-glucose co-transporter 2 (SGLT2) inhibitors, sulfonylureas, thiazolidinediones, and combinations of oral antidiabetic agents that were commercially available at the time of the study. Drugs used off-label to treat diabetes (e.g., bromocriptine) were not included.

ADD indicates anti-diabetic drug; BG, blood glucose; NQF, National Quality Forum.

**Table 2.**

Patient and Blood Glucose Event Characteristics Among a Random Sample of Inpatients Receiving Anti-Diabetic Drugs, 2016[*]

| Characteristics | Hospital A N (%) | Hospital B N (%) | Hospital C N (%) | All Hospitals N (%) |
|---|---|---|---|---|
| **Age in years** | | | | |
| 18–30 | 4 (3.7) | 4 (3.6) | 6 (5.9) | 14 (4.4) |
| 31–40 | 11 (10.1) | 12 (10.9) | 4 (3.9) | 27 (8.4) |
| 41–50 | 22 (20.2) | 10 (9.1) | 15 (14.7) | 47 (14.6) |
| 51–60 | 32 (29.4) | 23 (20.9) | 24 (23.5) | 79 (24.6) |
| 61–70 | 27 (24.8) | 32 (29.1) | 27 (26.5) | 86 (26.8) |
| >70 | 13 (11.9) | 29 (26.4) | 26 (25.5) | 68 (21.2) |
| **Female (%)** | 52 (47.7) | 54 (49.1) | 47 (46.1) | 153 (47.7) |
| **ADDs received <24 hours of blood glucose index event <54 mg/dL** [†] | | | | |
| Short-acting insulin[‡] | 55 (79.7) | 44 (62.9) | 25 (38.5) | 124 (60.8) |
| Non-short-acting insulin | 47 (68.1) | 44 (62.9) | 43 (66.2) | 134 (65.7) |
| Biguanide (Metformin) | 0 (0.0) | 1 (1.4) | 0 (0.0) | 1 (0.5) |
| Sulfonylurea | 2 (2.9) | 0 (0.0) | 2 (3.1) | 4 (2.0) |
| Other | 1 (1.4) | 0 (0.0) | 1 (1.5) | 2 (1.0) |
| **Inpatient location**[§] | | | | |
| ICU | 29 (26.6) | 34 (30.9) | 29 (28.4) | 92 (28.7) |
| Non-ICU | 80 (73.4) | 76 (69.1) | 73 (71.6) | 229 (71.3) |
| **Blood glucose source** | | | | |
| Capillary | 91 (83.5) | 89 (80.9) | 64 (62.8) | 244 (76.0) |
| Venous | 17 (15.6) | 21 (19.1) | 38 (37.2) | 76 (23.7) |
| Arterial | 1 (0.9) | 0 (0.0) | 0 (0.0) | 1 (0.3) |
| **Randomly sampled blood glucose** | | | | |
| <40 mg/dL | 40 (36.7) | 40 (36.4) | 39 (38.2) | 119 (37.1) |
| 40–53 mg/dL | 29 (26.6) | 30 (27.3) | 26 (25.5) | 85 (26.5) |
| ≥54 mg/dL | 40 (36.7) | 40 (36.4) | 37 (36.3) | 117 (36.4) |
| Total | 109 (33.8) | 110 (34.2) | 102 (31.8) | 321 (100.0) |

[*] Measure criteria modified as described in Table 1. Data are from a random sample of N = 321 patients (321 BG events) receiving anti-diabetic drugs during their hospitalization whose medical charts were reviewed for validation of the accuracy of electronic queries for capturing NQF measure 2363.

[†] Index event was defined as a randomly selected low (<54 mg/dl) blood glucose event.

[‡] Short-acting insulin included: insulin aspart, insulin glulisine, regular insulin, and insulin lispro; all other insulin products were classified as non-short-acting insulin.

[§] Refers to where hypoglycemia events occurred, rather than where preceding ADDs were administered.

ADD indicates anti-diabetic drug; ICU, intensive care unit

**Table 3.**

Performance Characteristics of Electronic Queries for Capturing NQF 2363 Criteria, 2016*

| | | | | Sensitivity (95% CI) | Specificity (95% CI) |
|---|---|---|---|---|---|
| **Measure Numerator** | | MCR+ | MCR- | | |
| Blood glucose <40 mg/dL | eCQM+ | 70 | 0 | 97.3% (90.5% – 99.7%) | 100.0% (92.6% – 100.0%) |
| | eCQM- | 2 | 47 | | |
| Blood glucose 40–53 mg/dL | eCQM+ | 55 | 0 | 98.2% (90.5% – 100.0%) | 100.0% (88.1% – 100.0%) |
| | eCQM- | 1 | 29 | | |
| Blood glucose <54 mg/dL | eCQM+ | 125 | 0 | 97.7% (93.3% – 99.5%) | 100.0% (95.3% – 100.0%) |
| | eCQM- | 3 | 76 | | |
| **Measure Denominator** | | MCR+ | MCR- | | |
| ADD days | eCQM+ | 506 | 4 | 91.8% (89.2% – 94.0%) | 99.0% (97.5% – 99.7%) |
| | eCQM- | 45 | 404 | | |

*Measure criteria modified as described in Table 1. Data are from a random sample of N = 321 patients (321 BG events) receiving anti-diabetic drugs during their hospitalization whose medical charts were reviewed for validation of the accuracy of the automated queries for capturing NQF measure 2363. MCR (+) refers to identification of a blood glucose event meeting all NQF numerator criteria based on manual chart review. MCR (−) refers to a blood glucose event not meeting all NQF numerator criteria, or a blood glucose event that meets NQF numerator criteria, but according to the medical chart, laboratory result is attributable to a measurement error and not a true hypoglycemia event. eCQM (+) refers to identification of a blood glucose event meeting all NQF numerator criteria based on electronic data queries. eCQM (−) refers to a blood glucose event not meeting all NQF numerator criteria, or a blood glucose event that fails to appear in the results of the electronic data queries.

ADD indicates anti-diabetic drug; CI, confidence interval, eCQM, electronic clinical quality measure; MCR, manual chart review

**Table 4.**

Hospital-wide and Unit-specific Hypoglycemia Event Rates as Defined by NQF 2363 Criteria and Captured by Electronic Queries, 2016 *

| Location | Blood Glucose Threshold | | | Event Rate (%), BG <40 mg/dL (95% CI) | Event Rate (%), BG <54 mg/dL (95% CI) |
|---|---|---|---|---|---|
| **All units** | **<40 mg/dL** | **<54 mg/dL** | **ADD days** | | |
| Hospital A | 134 | 473 | 20341 | 0.7 (0.6 to 0.8) | 2.3 (2.1 to 2.5) |
| Hospital B | 183 | 665 | 22147 | 0.8 (0.7 to 1.0) | 3.0 (2.8 to 3.2) |
| Hospital C | 78 | 340 | 17783 | 0.4 (0.4 to 0.5) | 1.9 (1.7 to 2.1) |
| **MICU** | | | | | |
| Hospital A | 10 | 26 | 1525 | 0.7 (0.3 to 1.2) | 1.7 (1.1 to 2.5) |
| Hospital B | 27 | 78 | 1699 | 1.6 (1.1 to 2.3) | 4.6 (3.6 to 5.7) |
| **SICU** | | | | | |
| Hospital A | 1 | 13 | 863 | 0.1 (0.0 to 0.6) | 1.5 (0.8 to 2.5) |
| Hospital B | 13 | 59 | 1724 | 0.8 (0.4 to 1.3) | 3.4 (2.6 to 4.4) |
| **Medical-surgical wards** | | | | | |
| Hospital A | 89 | 341 | 15144 | 0.6 (0.5 to 0.7) | 2.2 (2.0 to 2.5) |
| Hospital B | --- | --- | --- | --- | --- |
| **Medical wards** | | | | | |
| Hospital B | 53 | 195 | 6623 | 0.8 (0.6 to 1.0) | 2.9 (2.6 to 3.4) |

*Measure criteria modified as described in Table 1. Data are from a random sample of N = 321 patients receiving anti-diabetic drugs during their hospitalization. Unit-specific information was not available from hospital C. Hospital B does not have combined medical/surgical units.

ADD indicates anti-diabetic drug days; BG, blood glucose; CI, confidence interval; MICU, medical intensive care unit; SICU, surgical intensive care unit.